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EVALUATION OF BRAKING PERFORMANCE OF A LIGHT, TWIN-ENGINE AIRPLANE ON GROOVED AND UNGROOVED PAVEMENTS

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16. Abstract

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SUMMARY

The braking performance of a nine-place, light, twin-engine airplane was evaluated on comparative grooved and ungrooved surfaces of the landing research runway at NASA Wallops Station. The test airplane was equipped with manual braking on the main wheels of the tricycle landing gear, and its weight varied from 33.4 to 35.6 kN (7500 to 8000 lb). The test results indicate that pavement grooving significantly improves aircraft braking and directional control on wet runways. Measurements and observations of airplane tire treads made during this test program showed no indication of unusual wear and/or damage attributable to grooved surfaces. Comparative braking data obtained with a jet fighter and a civil and a military jet transport are also presented.

INTRODUCTION

It is generally recognized that the installation of transverse grooves in runway pavements provides improved tire traction under adverse weather conditions and thereby increases the safety of aircraft ground operations. The results from pavement grooving studies at the Langley landing-loads track (ref. 1) were sufficiently encouraging to effect the installation of a landing research runway at NASA Wallops Station, Virginia. This runway, described in reference 1, was constructed primarily to study the effects of pavement grooving on full-scale aircraft take-off and landing performance in simulated adverse weather conditions. Since March 1968, the NASA has been engaged in a research program to study the braking performance of various types of aircraft on the comparative grooved and ungrooved surfaces of the landing research runway. Test airplanes were selected for this research to provide a wide variation in the major parameters which affect braking performance; namely, airplane weight, landing-gear arrangement, braking system, and tire inflation pressure. The selected airplanes included a two-engine jet fighter (McDonnell Douglas F-4D), and two four-engine jet transports (Convair 990A and Lockheed C-141A) all of which were equipped with antiskid braking systems. The results from the braking performance studies of these airplanes are presented in references 1 to 5 and indicate that the braking capability under adverse weather conditions is significantly improved when the various pavements are transversely grooved.

The purpose of this report is to present the results from braking performance tests of the Beech Queen Air B80, a business-type airplane equipped with a manual braking system. Over 100 braking test runs were conducted with this airplane on the various test surfaces of the landing research runway under dry, wet, flooded, and ice-covered surface conditions. The results of these tests are presented in terms of braking friction coefficients computed from measurements recorded onboard the airplane. Information is also presented concerning the effects of braking on tire tread life and the airplane directional control on grooved and ungrooved surfaces.

Comparative braking data obtained with two jet transports and a jet fighter are presented in the appendix. The principal factors affecting the braking performance of each test airplane are listed to provide a basis for evaluating the braking test results.

SYMBOLS

Measurements for the dimensional quantities presented herein were originally taken in U.S. Customary Units but are presented also in the International System of Units (SI). Conversion factors relating the two systems of units are given in reference 6.

a_X	longitudinal acceleration, g units ($1g = 9.81\ \text{m/sec}^2 = 32.17\ \text{ft/sec}^2$)
D	total drag force (rolling resistance included), newtons (pounds)
F_Z	vertical force acting on main wheel axle, newtons (pounds)
p	tire inflation pressure, newtons/centimeter^2 (pounds/inch^2)
V_G	ground speed, knots
V_P	hydroplaning speed, knots
W	airplane weight, newtons (pounds)
μ	braking friction coefficient
μ_{eff}	effective braking friction coefficient (average μ developed by airplane as modified by pilot braking or antiskid braking system)
μ_{max}	maximum braking friction coefficient

APPARATUS

Test Airplane

The test airplane used in this braking investigation is the Beech Queen Air B80, a nine-place, twin-engine, low-wing monoplane with a gross test weight which varied between 33.4 and 35.6 kN (7500 and 8000 lb). The general geometric characteristics of the airplane are shown in figure 1.

The airplane is equipped with a tricycle landing gear incorporating hydraulic disk brakes on the main gear and a steerable, unbraked nose wheel. No electrical antiskid features are incorporated in the landing-gear design. In these tests, however, the available wheel braking torque was insufficient to cause wheel skidding on dry pavements.

The main-gear tires are type III, 8.50×10 and have a circumferential four-groove tread design, and the nose gear utilized a four-groove, type III, 6.50×10 tire. Inflation pressures for the main- and nose-gear tires were 32.4 and 24.1 N/cm^2 (47 and 35 lb/in^2), respectively.

Runway Surfaces

A schematic view of the landing research runway at NASA Wallops Station is presented in figure 2 together with photographs which give an indication of the texture of each of the nine test surfaces comprising the 1050-m (3450-ft) test section. A level (both transversely and longitudinally) 427-m (1400-ft) concrete section and a 427-m (1400-ft) asphalt section are separated by a 198-m (650-ft) Gripstop transition surface having a longitudinal slope of 0.1 percent. Each of the test surfaces, identified by code letters A to I, have surface treatments described as follows:

Surface A – Ungrooved concrete with canvas-belt drag surface finish
Surface B – Grooved concrete with canvas-belt drag surface finish
Surface C – Grooved concrete with burlap drag surface finish
Surface D – Ungrooved concrete with burlap drag surface finish
Surface E – Ungrooved rock asphalt (Gripstop)
Surface F – Ungrooved small-aggregate asphalt
Surface G – Grooved small-aggregate asphalt
Surface H – Grooved large-aggregate asphalt
Surface I – Ungrooved large-aggregate asphalt

Each test surface is 107 m (350 ft) in length except for surface E which is 198 m (650 ft). The grooves of surfaces B, C, G, and H are cut transversely in a geometrically similar pattern: 0.63 cm (1/4 in.) wide and deep, spaced 2.54 cm (1 in.) apart. The small and large aggregate used in the asphalt test surfaces refer to stone sizes less than 0.95 cm (3/8 in.) and 1.91 cm (3/4 in.), respectively. A more detailed description of the runway surfaces is given in reference 7.

The braking performance of the instrumented test airplane was evaluated on the comparative grooved and ungrooved test surfaces under dry surface conditions and under two different surface wetness conditions: namely, wet with isolated puddles and flooded to a water depth which ranged from 0.25 cm (0.1 in.) to 0.76 cm (0.3 in.). In addition, braking tests were conducted on the small-aggregate asphalt (surfaces F and G) under an ice-covered runway condition. Photographs of a test surface for the wet and the flooded test conditions are presented as figure 3.

An ice-covered test condition was achieved on the small-aggregate asphalt (surfaces F and G) by spraying water on these surfaces when the ambient temperature was -7.8° C (18° F) and allowing the water, both on the surface and in the grooves of surface G, to freeze. During a test run, the airplane braking distance for these ice-covered surface conditions was less than 53 m (175 ft).

Instrumentation

The test airplane was instrumented to measure and record continuous oscillograph traces of airplane attitude and accelerations, the angular velocity of the wheels, the brake-pedal pressures, and such information relative to the airplane braking characteristics as engine speed and the landing-gear shock-strut response. The main instrument package, shown in figure 4, was located near the airplane center of gravity and served as a mount for the accelerometers, attitude sensors, and recording equipment. Sample oscillograph records which show the measured responses during brake application on wet and flooded surfaces are reproduced in figure 5. Also identified in the figure are the relative airplane ground speeds and the runway test surfaces encountered during the test.

A visual display of right- and left-main-wheel ground speed was provided so that wheel lockups could be monitored during maximum-braking tests. This display also served to aid the pilot in achieving the desired test speed for brake application. In addition, extensive ground and aerial photographic coverage was used during the tests to monitor and record test events, airplane motions (such as lateral drifting and weather cocking), and the behavior of the main-landing-gear system.

TEST PROCEDURE

The testing technique consisted of taxiing the airplane at preselected ground speeds onto the desired runway test section, applying maximum braking, and recording the airplane response. Prior to these braking performance tests, the airplane was operated at various constant ground speeds over a measured distance to permit a calibration of the ground-speed instrumentation. In addition, free-roll tests (propellers windmilling) were performed on the different surfaces to evaluate the total airplane drag at ground speeds corresponding to those encountered during the braking tests.

The braking tests were conducted with propellers windmilling and, in general, included half of two adjacent grooved and ungrooved test surfaces of similar surface composition (e.g., surfaces A and B) to permit a comparison of the runway surface treatment at a consistent brake-pedal pressure. This technique subjected the test airplane to heavy braking for a distance of approximately 107 m (350 ft). The relatively small braking distance was desirable since the airplane was found to be highly responsive to cross winds during braking on low-friction surfaces at speeds below minimum rudder-control speed (approximately 80 knots). Comparative braking effectiveness data were collected at ground speeds which ranged from approximately 20 to 110 knots.

PRESENTATION OF DATA

Data describing each airplane braking test were obtained from an oscillograph record of the outputs of the onboard instruments. The sample records reproduced in figure 5 typify the data which include a time history of airplane accelerations, brake pressures, and the corresponding angular velocities of each main-gear wheel. Also included in the figure are the nature of the runway surface and the airplane ground speed. The ground speed throughout each test run was determined by using an onboard ground-speed indicator to obtain the initial velocity prior to brake engagement and then integration of the longitudinal deceleration to provide the velocity time history. The brake-pressure trace identifies the time and extent of brake application, and the wheel-velocity trace is used to denote wheel lockups (when wheel rotational velocity equals zero). The magnitude of the longitudinal deceleration is a measure of the braking effectiveness of the airplane for a particular test condition.

To evaluate the braking performance of the aircraft, the effective braking friction coefficient μ_{eff} was computed from the equation of motion which described the forces on the airplane while it is operating with windmilling propellers (thrust approximately equal to zero). This equation is

$$Wa_X = D + \mu_{eff} F_Z$$

where W is the airplane weight, a_X is the longitudinal acceleration in g units (taken from the oscillograph record), D is the total drag (rolling resistance included) on the airplane determined from free-roll tests at various ground speeds, and F_Z is the vertical load on the main-gear tires as computed from the recorded strut pressures. The variation of wheel loading with ground speed is typified by the data in figure 6. Thus, μ_{eff} can be expressed

$$\mu_{eff} = \frac{1}{F_Z}\left(Wa_X - D\right)$$

Effective braking friction coefficients, computed from each test, are presented as a function of ground speed V_G in figure 7 to permit an evaluation of the braking performance of the airplane for different wetness conditions on the various grooved and ungrooved runway surfaces. Figure 8 shows braking data from solid-ice-covered runway surfaces. Figure 9 is a summary of the test results which illustrates the effect of runway surfaces on the Queen Air airplane braking performance.

Figure 10 is a reproduced oscillograph record presented to show the effect of braking performance on the directional control of the airplane operating in a cross wind. The photographs in figure 11 illustrate the extent of tire wear during the course of the test program.

Braking data obtained from other instrumented airplanes (a jet fighter and two jet transports) tested on the landing research runway together with data for the Queen Air airplane are presented in the appendix.

RESULTS AND DISCUSSION

The braking test program for the Queen Air airplane was one phase of a continuing research program to evaluate the effects of pavement grooving on aircraft landing and take-off performance under adverse weather conditions. In performing this evaluation, the pavement grooving effects on aircraft braking performance, directional control, and tire tread life were studied.

Braking Performance

The test-airplane braking performance under adverse weather conditions on grooved and ungrooved pavements was evaluated from oscillograph records similar to those in figure 5. The records in this figure were taken as the airplane entered the large-aggregate asphalt test surfaces at approximately 90 knots. An examination of the traces in figure 5(a) shows that the wheels of the airplane locked up, with an accompanying loss in braking deceleration, upon departing the grooved portion of the asphalt runway when the surface was wet with isolated puddles. The traces in figure 5(b), however, indicate wheel spin-down to a low level following full brake-pressure application while the airplane was traversing the flooded grooved surface and indicate complete wheel lockup during operation on the flooded ungrooved surface. The airplane deceleration level indicates some braking effectiveness on the grooved surface, whereas the brakes were essentially ineffective in retarding the progress of the airplane on the ungrooved surface, flooded or wet, at this test ground velocity.

The variation of main-gear and nose-gear wheel loading on the test airplane with ground speed is indicated by the data in figure 6. These data were obtained during a free-rolling (propellers windmilling) test run with the airplane in the normal test configuration (0° flaps) on a dry runway. As the ground speed increases, the positive wing lift forces also increase until at a ground speed of 100 knots the initial total wheel loading of 32.9 kN (7400 lb) is reduced to 21.4 kN (4800 lb). This variation in wheel loading with ground speed was considered in calculating the effective airplane braking friction coefficient.

The variation in the effective airplane braking friction coefficient μ_{eff} with ground speed V_G is presented in figure 7 for the different runway test surfaces under both the wet and the flooded test conditions and in figure 8 for the ice-covered runway surface condition. For many of these braking tests under low-traction conditions, the maximum torque imparted to the wheels by the friction developed at the tire-ground interface was well below the maximum available torque of the pilot-modulated braking system, which resulted in wheel lockups. These data are identified in figures 7 and 8. Also included in these figures is a faired curve describing the airplane dry braking effectiveness level which, since it did not significantly vary with runway surface (grooved or ungrooved), represents data for all the test surfaces. The data of figure 7 show that the braking performance of the Queen Air airplane is substantially better (higher μ_{eff}) on the grooved surfaces than on similar ungrooved surfaces for both wetness conditions. This improvement in braking performance attributed to grooving is much more pronounced on the wet surfaces than on the flooded. The rapid decrease in braking effectiveness with increasing speed noted in the data for the flooded surfaces, particularly those ungrooved, is indicative of tire hydroplaning and the associated traction losses (see refs. 8 to 14). The hydroplaning speed for the tires of this airplane, as predicted by the method outlined in reference 15, is 61.7 knots.

The effects of runway surface water depth on the braking performance of the test airplane can be obtained by comparing the data from the wet and the flooded surfaces as presented in figure 7. These data indicate that, in general, the braking performance over the range of test ground speeds above approximately 20 knots is decreased with increased water depth. The braking friction level of the airplane was reduced to near zero for the flooded test surfaces at speeds greater than that predicted for hydroplaning.

The effect of runway grooves on airplane braking traction for a solid-ice-covered surface is shown in figure 8 as a function of ground speed. These data, all obtained under locked-wheel conditions, indicate that airplane braking capability was greatly reduced from that measured under dry surface conditions on both the ungrooved and grooved surfaces. Because of the solid-ice-covered surface condition, the test-airplane braking performance was insensitive to the type of runway surface.

The faired curves of figure 7 are summarized in figure 9 for both test wetness conditions to permit an evaluation of the relative braking performance of the test airplane on the different runway surfaces. The figure shows that the airplane braking-friction-coefficient levels obtained on the grooved surfaces are generally higher than those obtained on ungrooved surfaces throughout the test speed range. The variation in test-airplane braking data obtained on the five ungrooved surfaces under the wet condition with isolated puddles can be attributed to differences in runway surface texture of roughness. By using the grease technique described in reference 14, the average depth of the runway surface texture was measured near the runway center line and varied as follows: 0.12 mm for surface A, 0.20 mm for surface D, 0.14 mm for surface E, 0.19 mm for surface F, and 0.32 mm for surface I. Except for surface E (Gripstop), the data in figure 9(a) indicate that airplane wet braking capability is improved as surface texture depth is increased. Under flooded surface conditions (fig. 9(b)), the effect of surface texture on airplane braking performance is greatly diminished, especially at speeds above the critical hydroplaning speed.

Directional Control Considerations

During aircraft landings or aborted take-offs, loss in steering or side-force capability can become just as critical as loss in braking capability, if not more so. Research has shown that during heavy braking on slippery runway surfaces wheel lockups can occur which reduce lateral traction to zero. In the presence of a cross wind, the safety of an aircraft operating under these conditions at speeds below effective aerodynamic control is in serious jeopardy.

During the braking test program with the Queen Air airplane, test data, visual observations, photographic coverage, and pilot comments indicated that runway grooves enabled the pilot to maintain or regain directional control during wet or flooded braking, particularly at ground speeds insufficient for aerodynamic directional control. An illustration of this airplane losing directional control during maximum braking on a flooded ungrooved surface and regaining control on a flooded grooved surface is presented in figure 10. This figure is a reproduction of an oscillograph record of the airplane traversing first a dry surface and, subsequently, flooded ungrooved and grooved surfaces, throughout which maximum braking was applied. Cross-wind velocity for this example was approximately 4 knots from the right. The figure shows that the airplane entered the flooded ungrooved surface on a straight course with good braking traction as evidenced by the traces which define airplane yaw angle and longitudinal acceleration. Evaluation of the aerial photographic coverage of this particular test run revealed that the right side of the runway surface was wet ahead of the assigned flooded ungrooved asphalt test surface, which accounts for the spin-down of the right main wheel on the dry surface as shown in the figure. However, continued braking on the flooded ungrooved surface resulted in spin-down of both main wheels to the locked-wheel condition (note the wheel-velocity traces) accompanied by a rapid decrease in braking traction as indicated by the low longitudinal acceleration level. In addition, during this portion of the test the airplane is shown to experience a severe yaw condition as noted in the yaw-angle trace, despite pilot corrections using nose-wheel steering and rudder deflection. The airplane then entered the flooded grooved surface under these hazardous conditions, and the record shows that main-wheel spin-up occurred immediately and the airplane braking traction and directional control was regained.

Tire Tread Wear

The test airplane was equipped with four-groove, type III, 8.50×10, all-rubber-tread main-gear tires whose inflation pressure was maintained at 32.4 N/cm^2 (47 lb/in^2). Although tire-tread-wear data collected during these tests are insufficient to make a rigorous comparison of the wear rate on grooved and ungrooved runways, it should be noted that 107 hard braking tests were all made with one set of tires which showed no visible signs of unusual damage attributable to grooves. Figure 11 provides a visual comparison of these tires before and after the test program. Tire tread depth measurements at points around the circumference of the tire indicated that approximately 63 percent of the tire tread remained after this test program. Under normal operations of the test airplane where heavy braking is used only in an emergency, the average tire life is approximately 150 landings. Furthermore, contrary to findings from other airplanes (ref. 3, for example), no chevron cuts were observed in the test tires in this program which included several airplane touchdowns and locked-wheel braking test conditions on grooved surfaces. However, it should be noted that the airplane of reference 3 (a Convair 990) had a touchdown speed of approximately 140 knots, a main-gear tire size of 41×15.0-18, and a main-gear tire inflation pressure of 110 N/cm^2 (160 lb/in^2) – all values being substantially higher than the corresponding values for the test airplane (approximately 100 knots, 8.50×10, and 32.4 N/cm^2 (47 lb/in^2)). The results from this limited comparison indicate that aircraft touchdown speed, tire size, and/or tire inflation pressure are factors which could affect the propagation of chevron cutting of tire treads on transversely grooved runways.

CONCLUDING REMARKS

The Queen Air airplane braking test results obtained on dry, wet, flooded, and ice-covered surfaces, grooved and ungrooved, at the landing research runway at NASA Wallops Station have substantiated and supplemented test results obtained with a civil and military jet transport and a jet fighter. The comparative airplane braking test results indicate that transverse runway grooves provide greatly increased braking capability and directional control under adverse weather conditions.

In this continuing effort to obtain a comprehensive evaluation of the effects of pavement grooving on airplane braking performance, it is recognized that airplane tire tread wear and/or damage is a potential problem area. However, for the test conditions, the main-gear tires on the Queen Air airplane did not appear to experience any unusual wear or damage attributable to runway grooving.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., August 3, 1971.

APPENDIX

RELATIVE BRAKING PERFORMANCE OF FOUR TEST AIRPLANES

In this appendix the relative braking performance of the four test airplanes employed in the research program to evaluate the comparative braking response on grooved and ungrooved runway surfaces is discussed and summarized. These airplanes were a McDonnell Douglas F-4D, a Convair 990A, a Lockheed C-141A, and the Beech Queen Air B80; the major factors which contribute to the braking performance are shown in table I.

Differences are noted in the landing-gear configuration, gross weight, and tire inflation pressure of these airplanes; however, the difference which is perhaps most significant with respect to braking performance is the braking system. All test airplanes were equipped with antiskid braking systems except for the Queen Air which was equipped with pilot-modulated and torque-limited brakes.

The maximum available friction coefficient for aircraft tires on a dry runway surface can be approximately predicted by an empirical expression as developed in reference 16. The equivalent equation used in this paper is

$$\mu_{max} = 0.93 - 0.0011p$$

where p is the tire inflation pressure in pounds/inch^2. The maximum friction coefficients for the tires of the different test airplanes were calculated from this expression and are summarized in the following table:

Test airplane	p, N/cm^2 (lb/in^2)	μ_{max}
Queen Air	32.4 (47)	0.88
C-141A	75.8 (110)	.81
990A	110 (160)	.75
F-4D	193 (280)	.62

By assuming that these values are realistic estimates of the maximum friction coefficient available to each airplane, an indication of the efficiency of the various braking systems can be obtained by comparing this maximum friction coefficient with the effective friction coefficients measured during the test program. This comparison in the form of airplane dry braking efficiency is presented in figure 12 where the ratio of the effective friction coefficient μ_{eff} to the calculated maximum available friction coefficient μ_{max}

is shown as a function of ground speed. The data for the F-4D, 990A, and C-141A airplanes were obtained from reference 5. Figure 12 shows that the Queen Air airplane, with manual braking, has a lower braking efficiency (45 to 53 percent) over most of the ground speed range than the other test airplanes which were equipped with antiskid braking systems. In general, the 990A and C-141A airplanes, equipped with multiple-wheel landing gears and antiskid braking systems, provided the best overall braking efficiency, but it should be noted that their dry braking performance level did not exceed 70 percent of the computed maximum available friction coefficient. The F-4D airplane dry braking efficiency decreased rapidly with speed from approximately 80 percent at low speed to less than 30 percent at high speed.

Figure 13 typifies the loss in braking performance resulting from wet runway operations as determined from each test airplane on grooved and ungrooved small-aggregate asphalt (surfaces F and G). This loss in braking is depicted by dividing the wet braking friction coefficient by the corresponding dry braking friction coefficient at the same ground speed. To provide a meaningful comparison between the different test airplanes, this ratio μ_{wet}/μ_{dry} is plotted as a function of the ratio of ground speed to hydroplaning speed since the hydroplaning speed for each airplane was different (see table I). The data for the F-4D, 990A, and C-141A were obtained from reference 5. Figure 13 shows that the Queen Air airplane experiences less degradation in braking effectiveness than the other airplanes for ground speeds up to and slightly beyond the hydroplaning speed. However, this lower degradation might be partially explained by the lower efficiency of the manual braking system of the Queen Air airplane on dry runway surfaces. The data of figure 13 also indicate that grooving a runway surface substantially improved the braking performance of all the test airplanes on wet and flooded runways.

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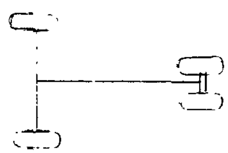
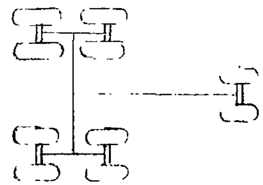
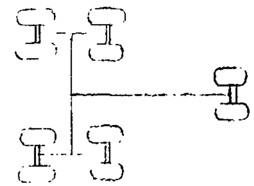
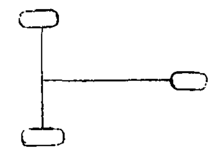
TABLE I.- FACTORS AFFECTING BRAKING PERFORMANCE OF AIRPLANES TESTED ON THE LANDING RESEARCH RUNWAY AT NASA WALLOPS STATION

Factor	Test airplanes			
	F-4D two-engine jet fighter	990A four-engine jet transport	C-141A four-engine jet transport	Queen Air twin engine (piston)
Landing-gear configuration				
Brake system	Antiskid (main wheels only)	Antiskid (nose and main wheels)	Antiskid (main wheels only)	Manual (main wheels only)
Gross weight, kN (lb)	160 (36 000)	712 (160 000)	847 (190 000)	33.4 to 35.6 (7500 to 8000)
Main-gear tire inflation pressure, N/cm^2 (lb/in^2)	193 (280)	110 (160)	75.8 (110)	32.4 (47)
Dynamic hydroplaning speed, knots	150	114	94	62

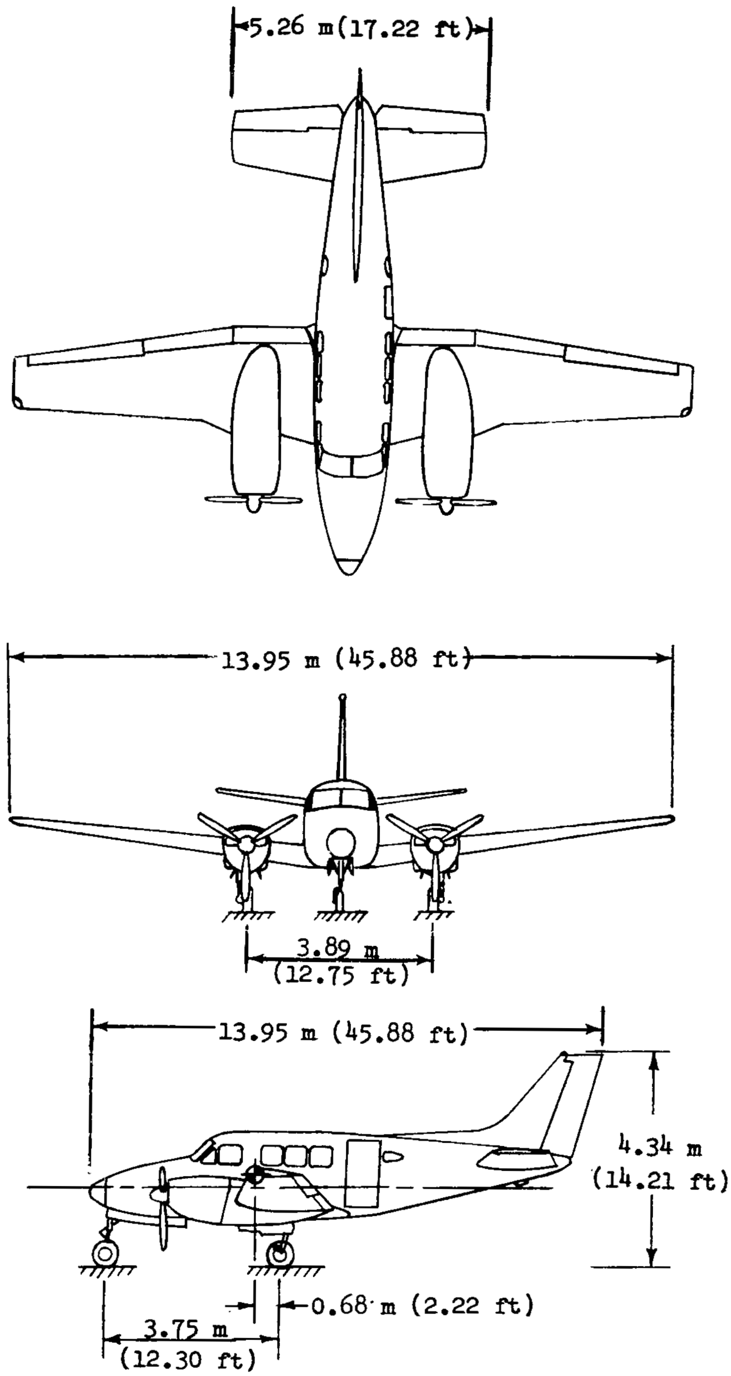


Figure 1.- General exterior configuration of test airplane.

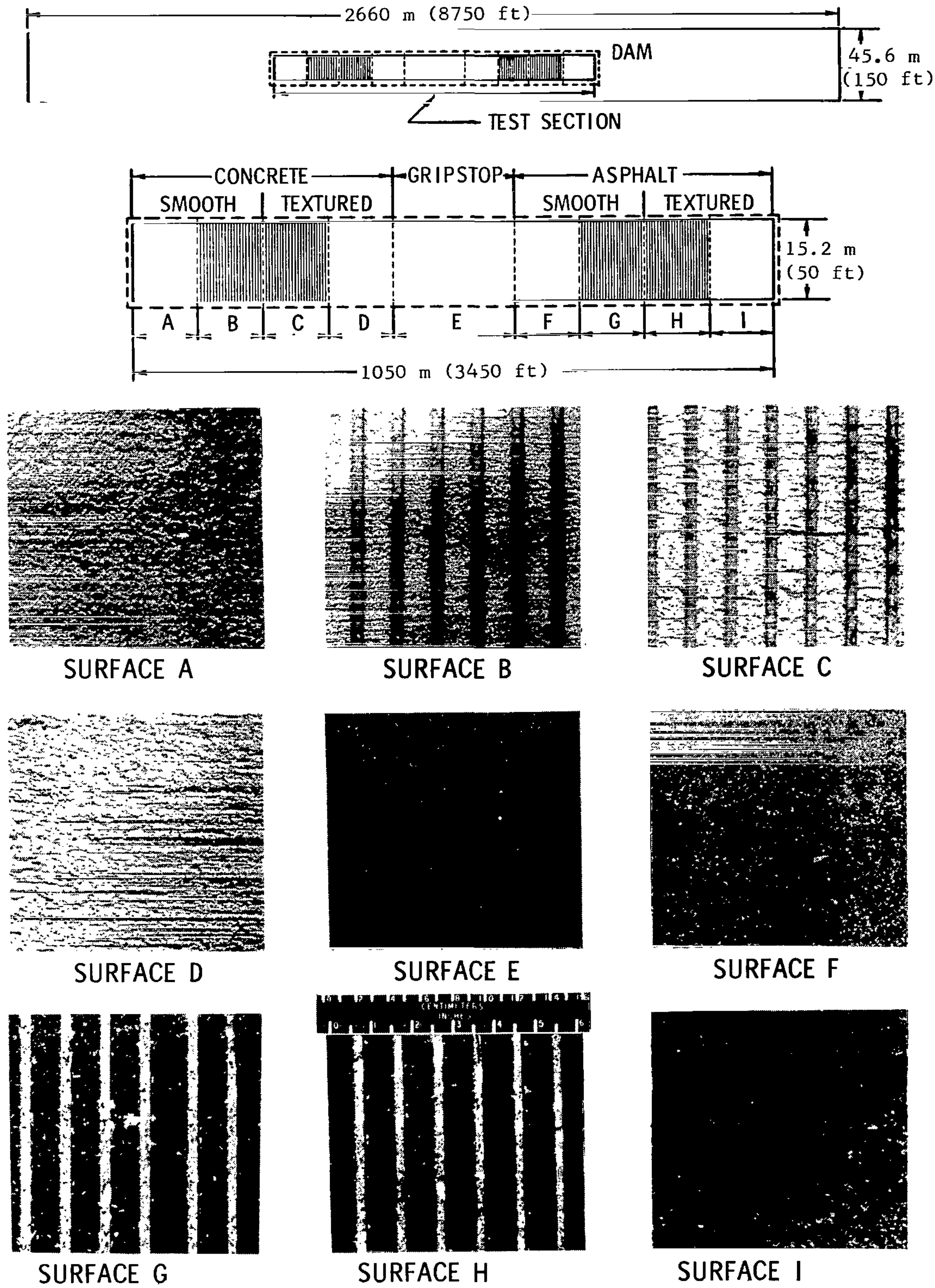


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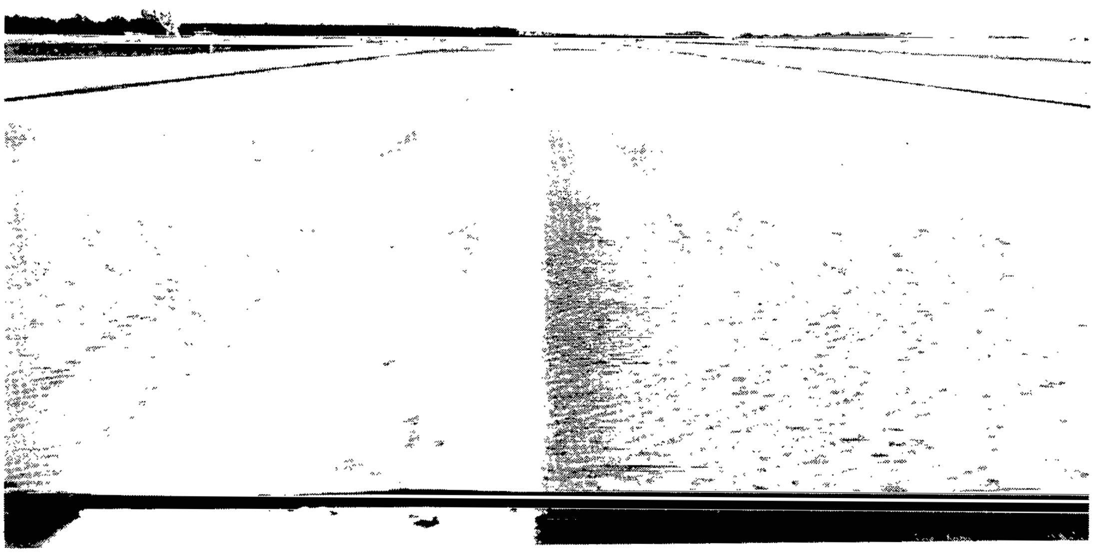
Figure 2.- Landing research runway at NASA Wallops Station.

(a) Wet with isolated puddles.



(b) Flooded (0.25 to 0.76 cm (0.1 to 0.3 in.)).

L-71-665

Figure 3.- Surface wetness conditions on test sections of landing research runway.

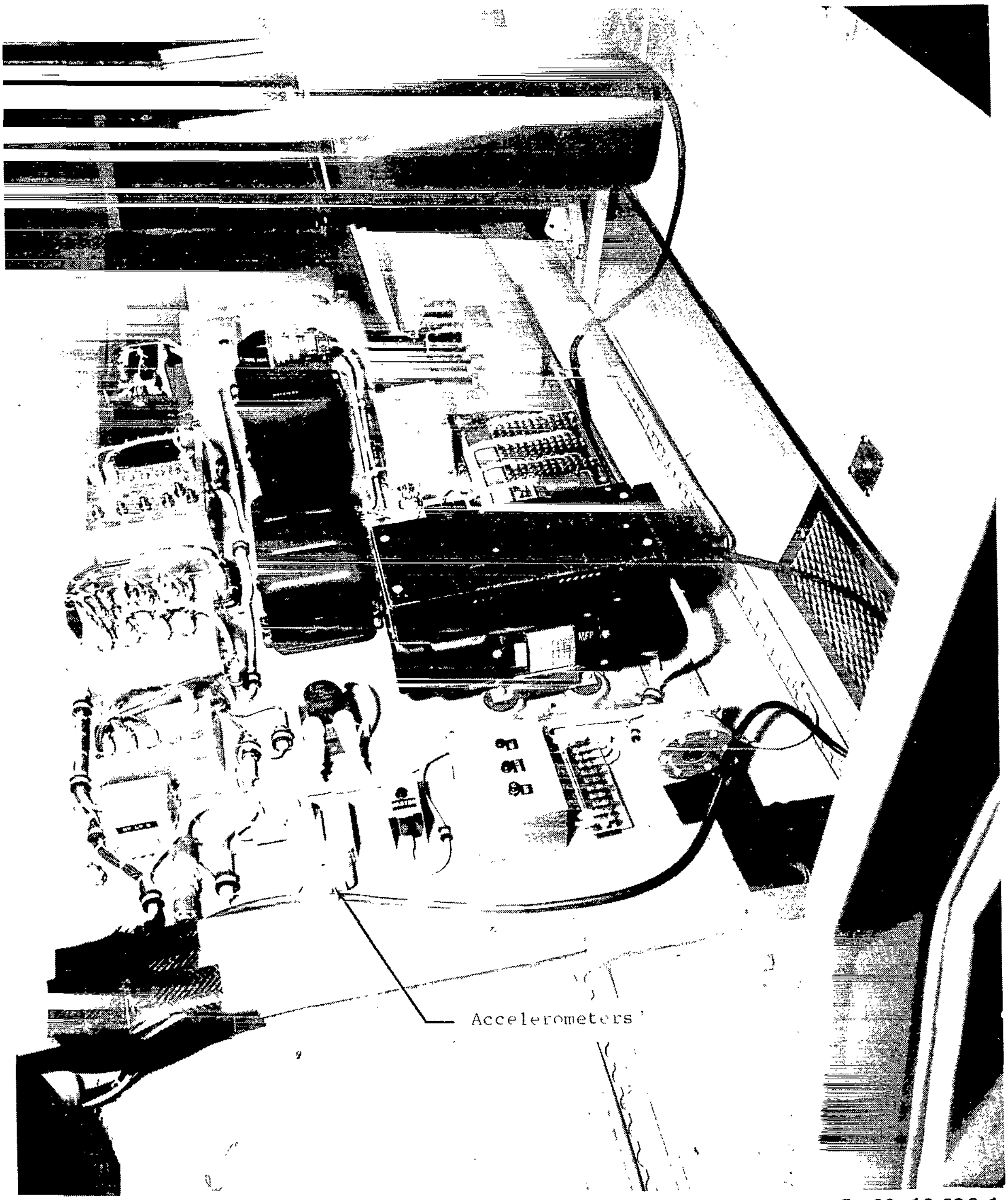


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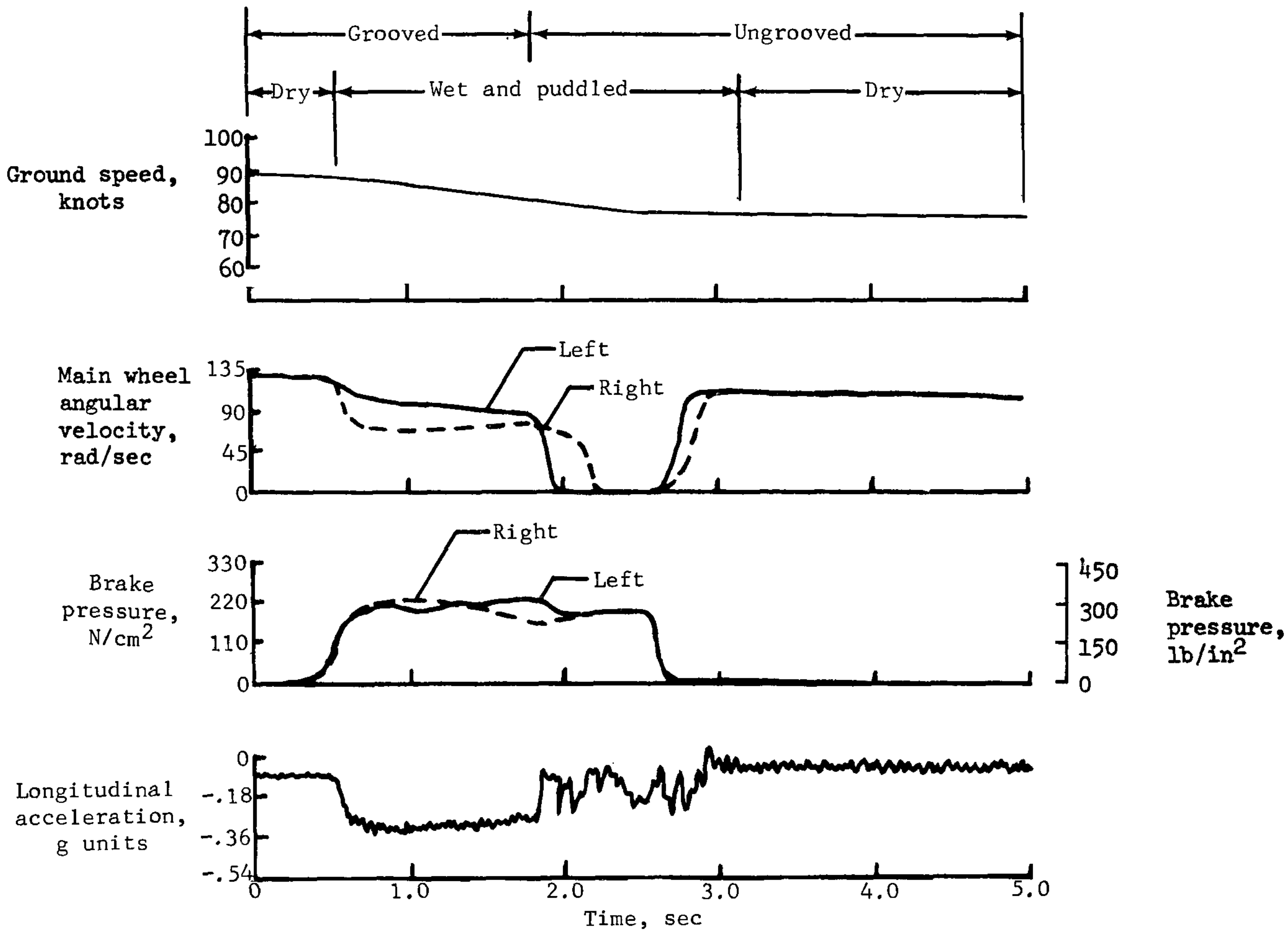
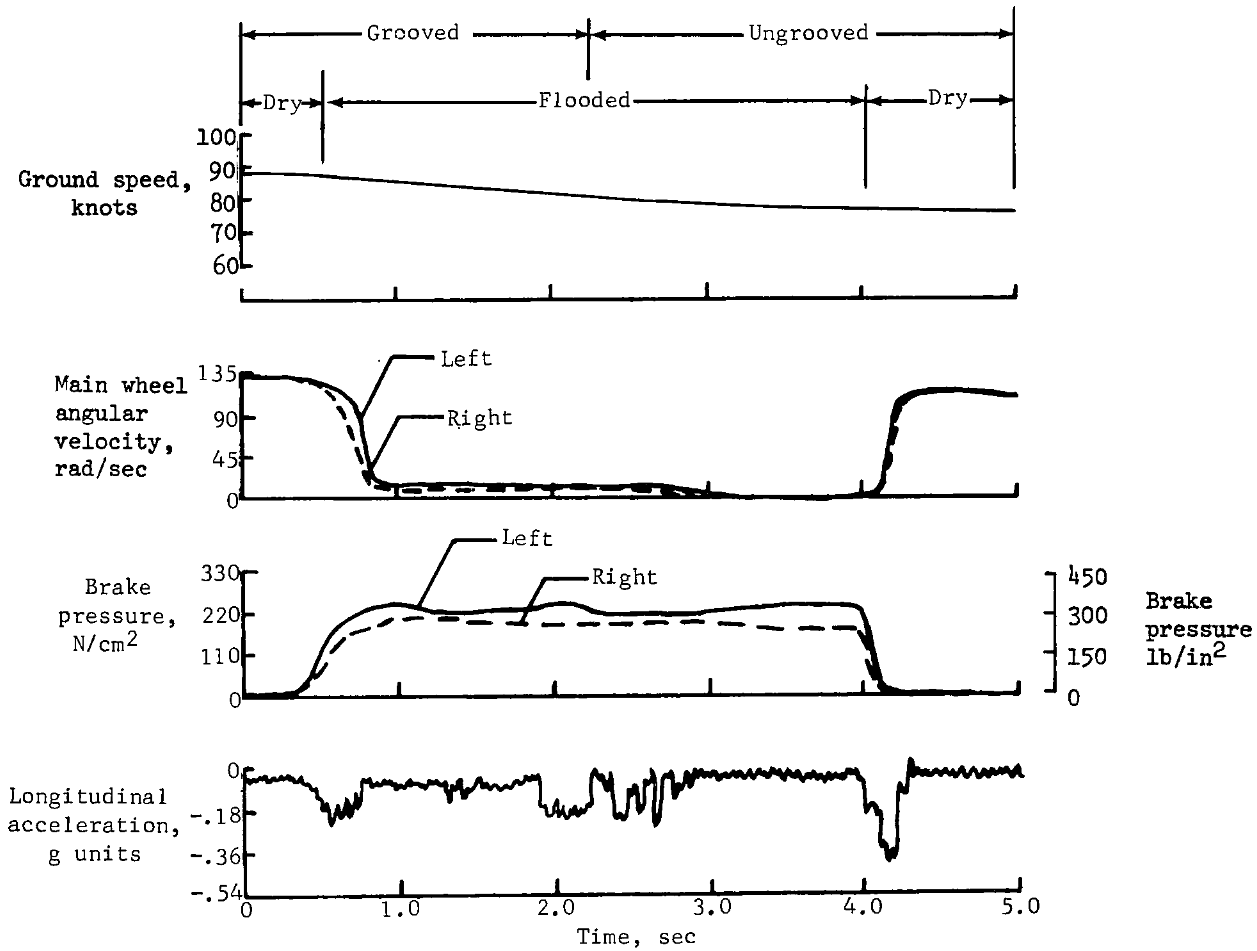
Figure 4.- Main instrument package onboard test airplane.



(a) Wet with isolated puddles.

Figure 5.- Sample oscillograph records showing some measured responses of test airplane during brake application on grooved and ungrooved surfaces. Large-aggregate asphalt.



(b) Flooded.

Figure 5.- Concluded.

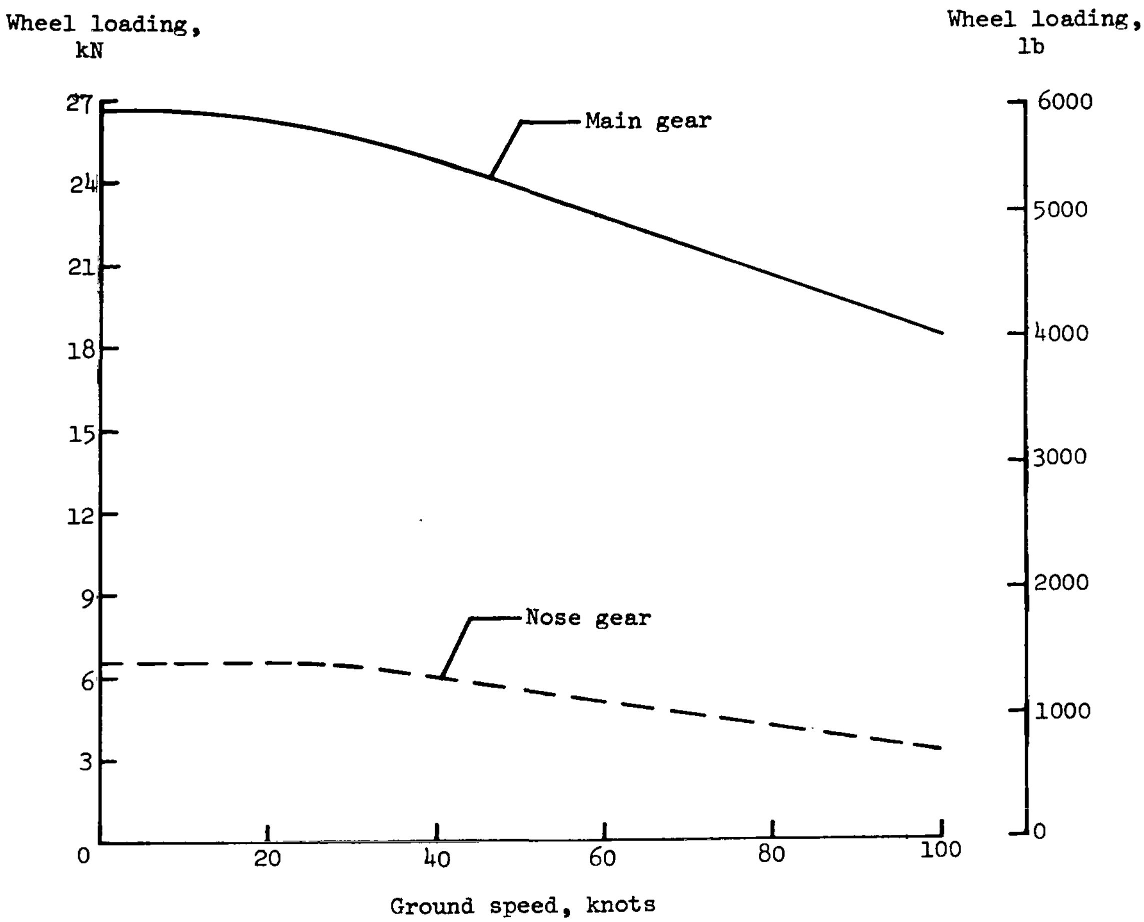
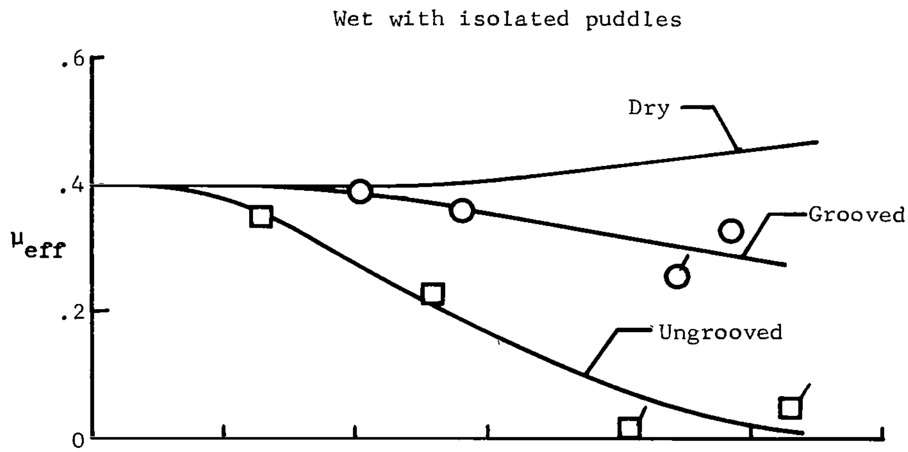
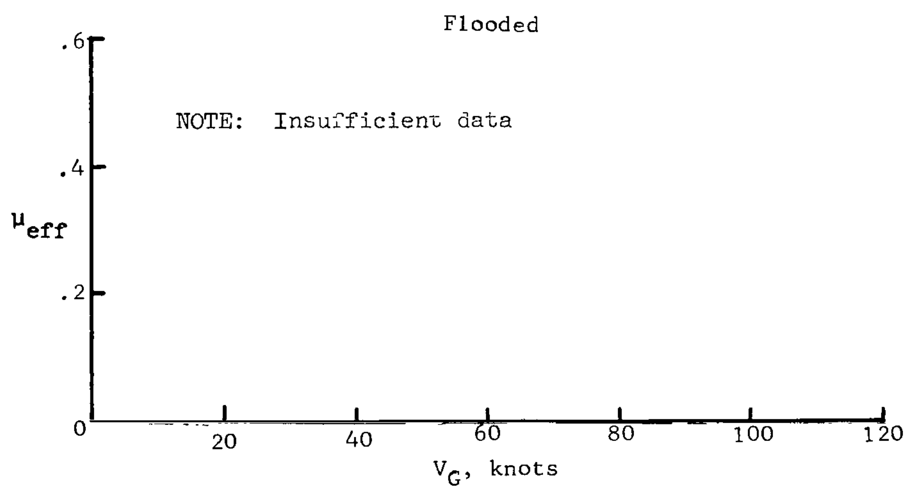


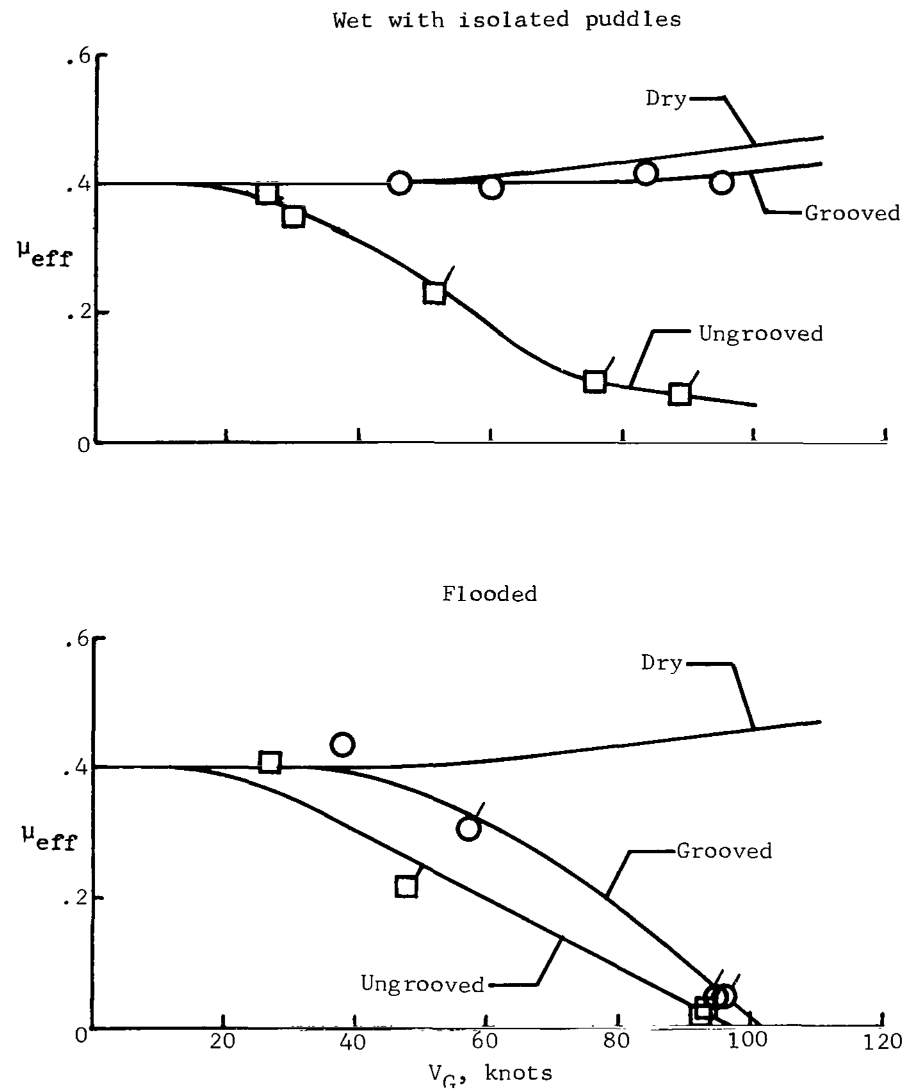
Figure 6.- Variation of test-airplane wheel loading with ground speed. Gross weight, 32.9 kN (7400 lb); free rolling (propellers windmilling); take-off configuration (0° flaps); no wind; dry surface.





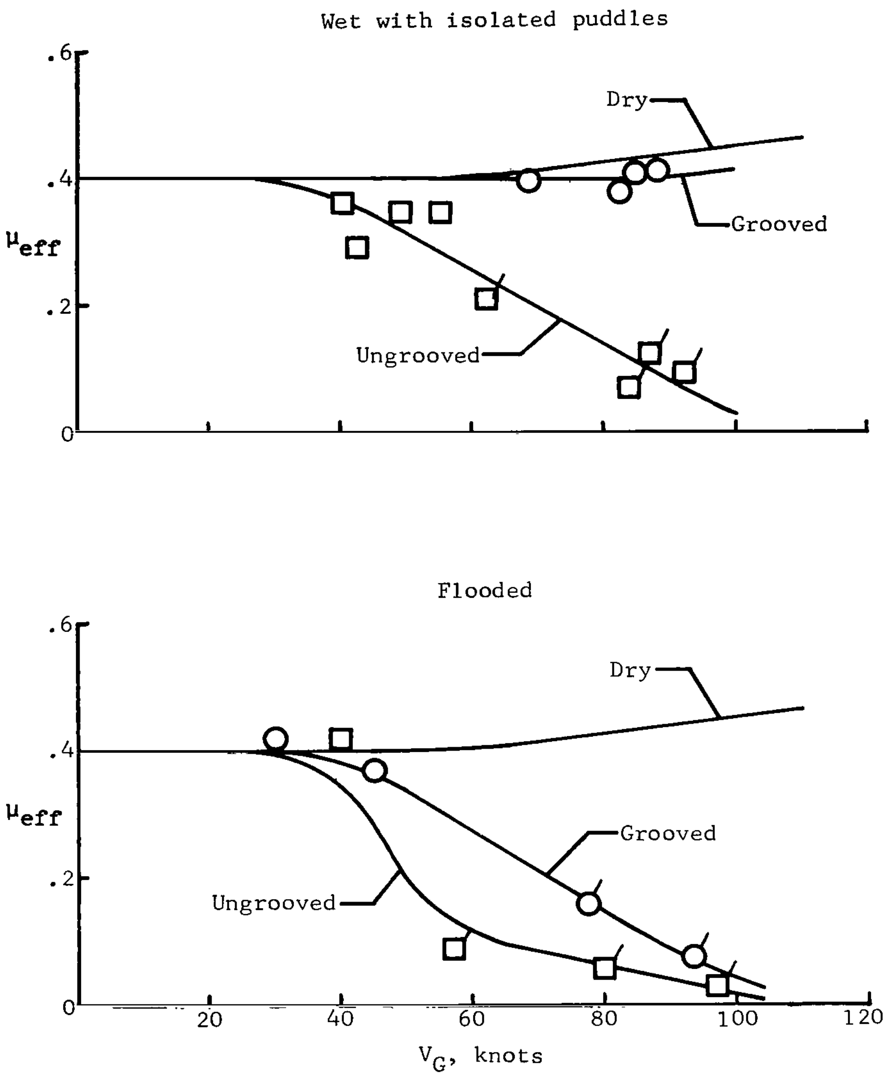
(a) Canvas-belt drag finished concrete; surfaces A (ungrooved) and B (grooved).

Figure 7.- Variation of test-airplane effective braking friction coefficient with ground speed under different surface wetness conditions. (Curve for dry surface condition included for comparison.) Flagged symbols indicate locked-wheel conditions.



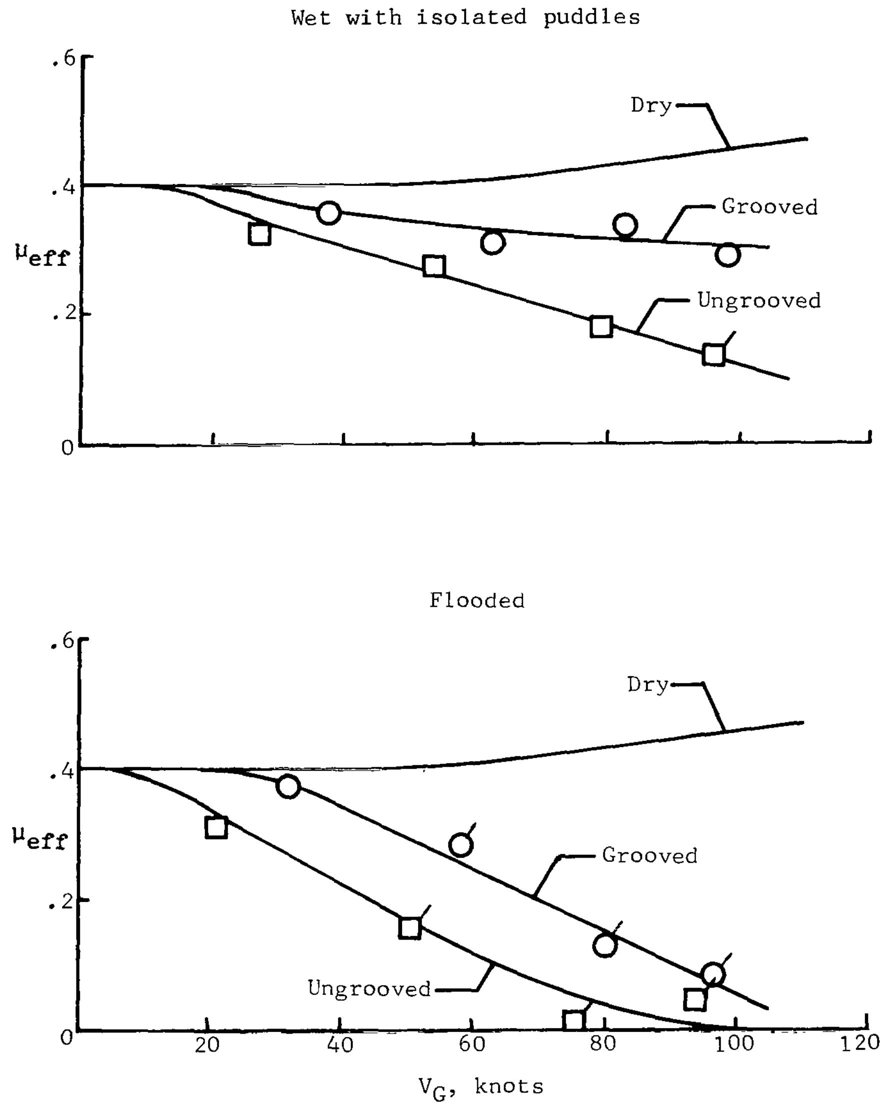
(b) Burlap drag finished concrete; surfaces C (grooved) and D (ungrooved).

Figure 7.- Continued.



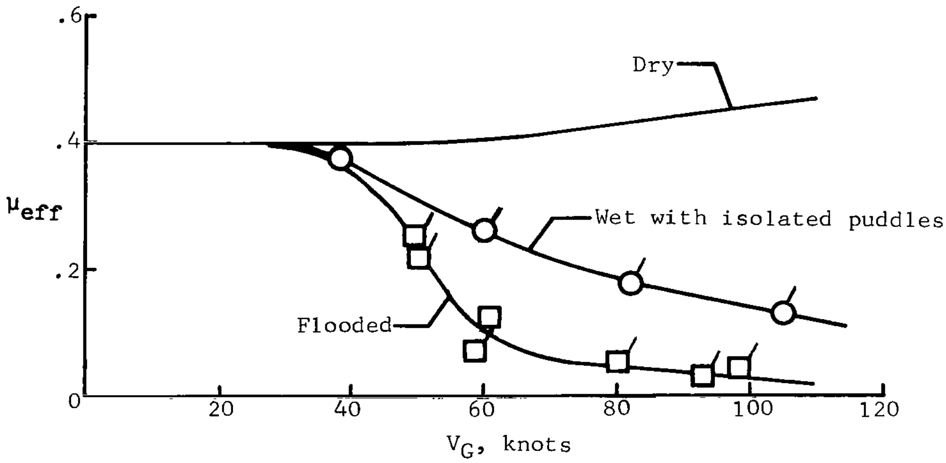
(c) Small-aggregate asphalt; surfaces F (ungrooved) and G (grooved).

Figure 7.- Continued.



(d) Large-aggregate asphalt; surfaces H (grooved) and I (ungrooved).

Figure 7.- Continued.



(e) Gripstop (surface E).

Figure 7.- Concluded.

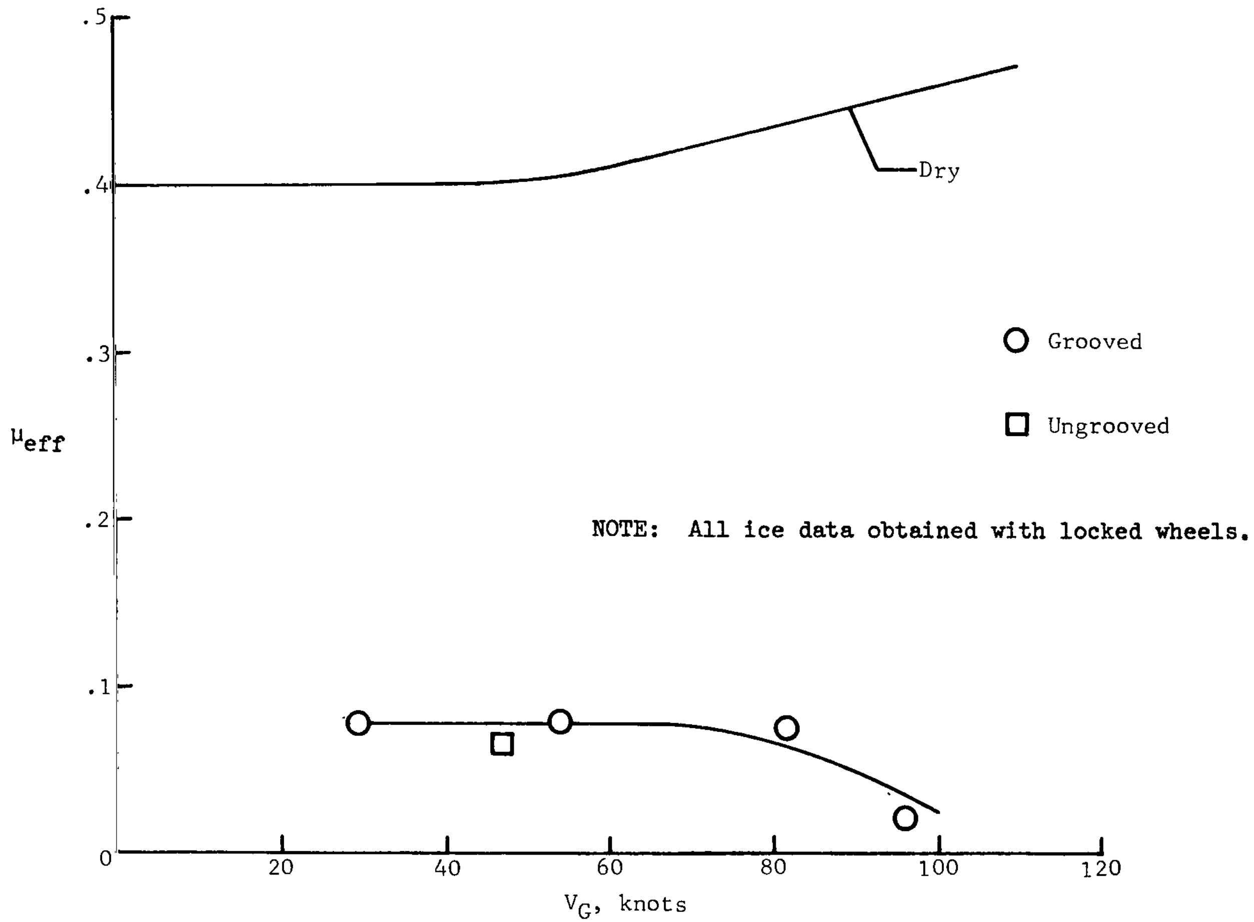
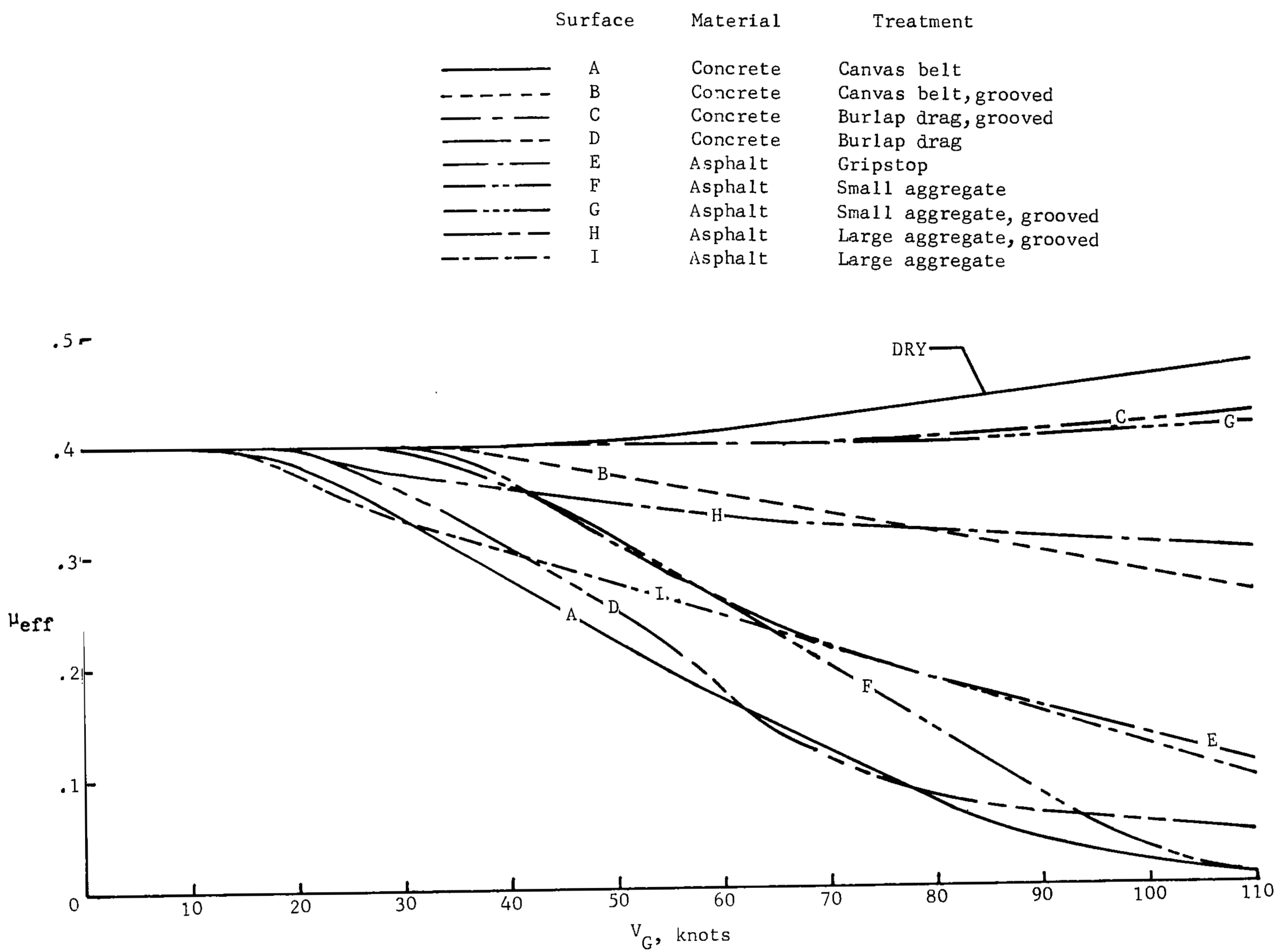
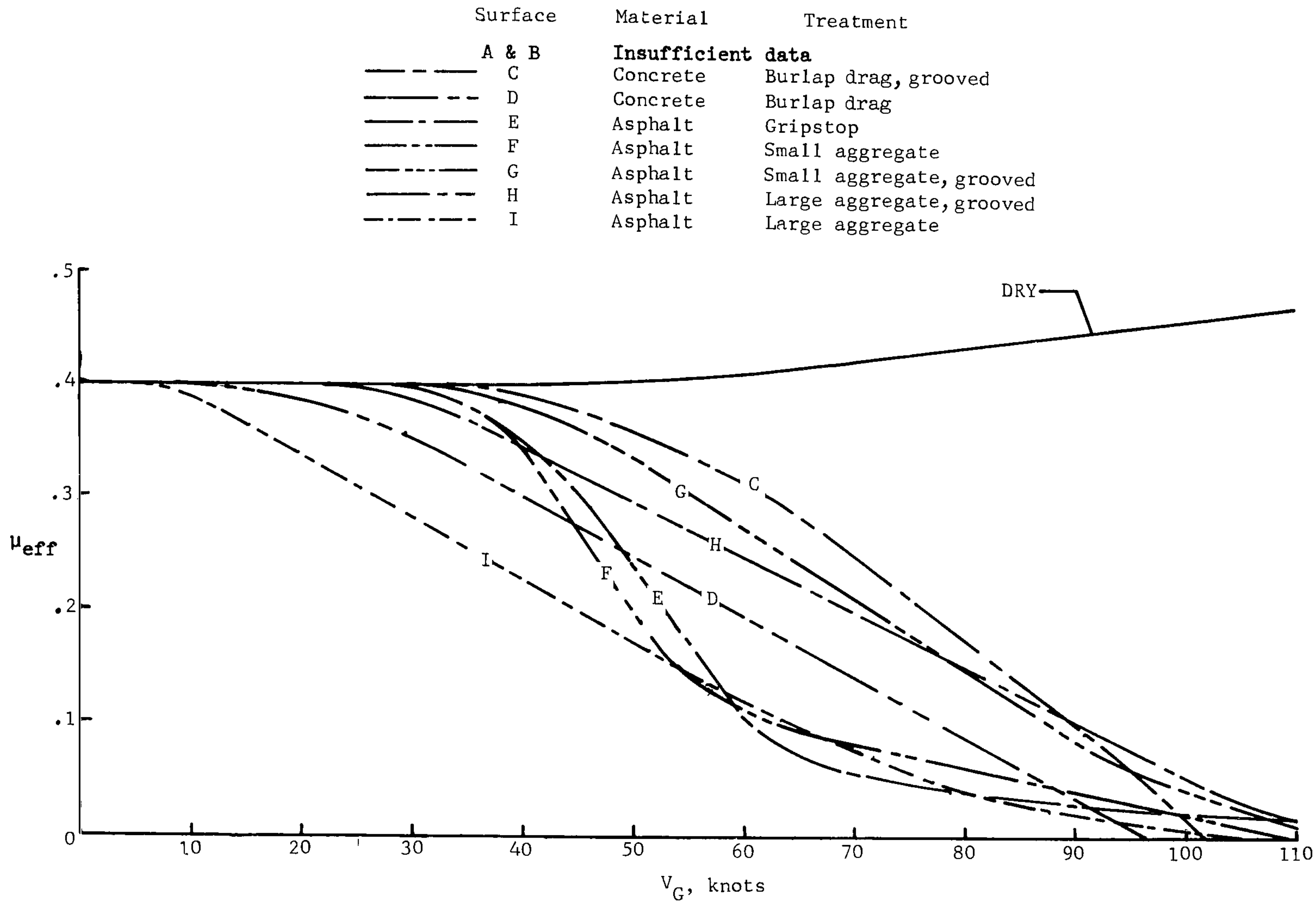


Figure 8.- Effect of solid-ice-covered surface condition on test-airplane effective braking friction coefficient. Small-aggregate asphalt; ambient temperature, -7.8° C (18° F).



(a) Wet with isolated puddles.

Figure 9.- Effect of runway test surfaces on test-airplane braking performance.



(b) Flooded.

Figure 9.- Concluded.

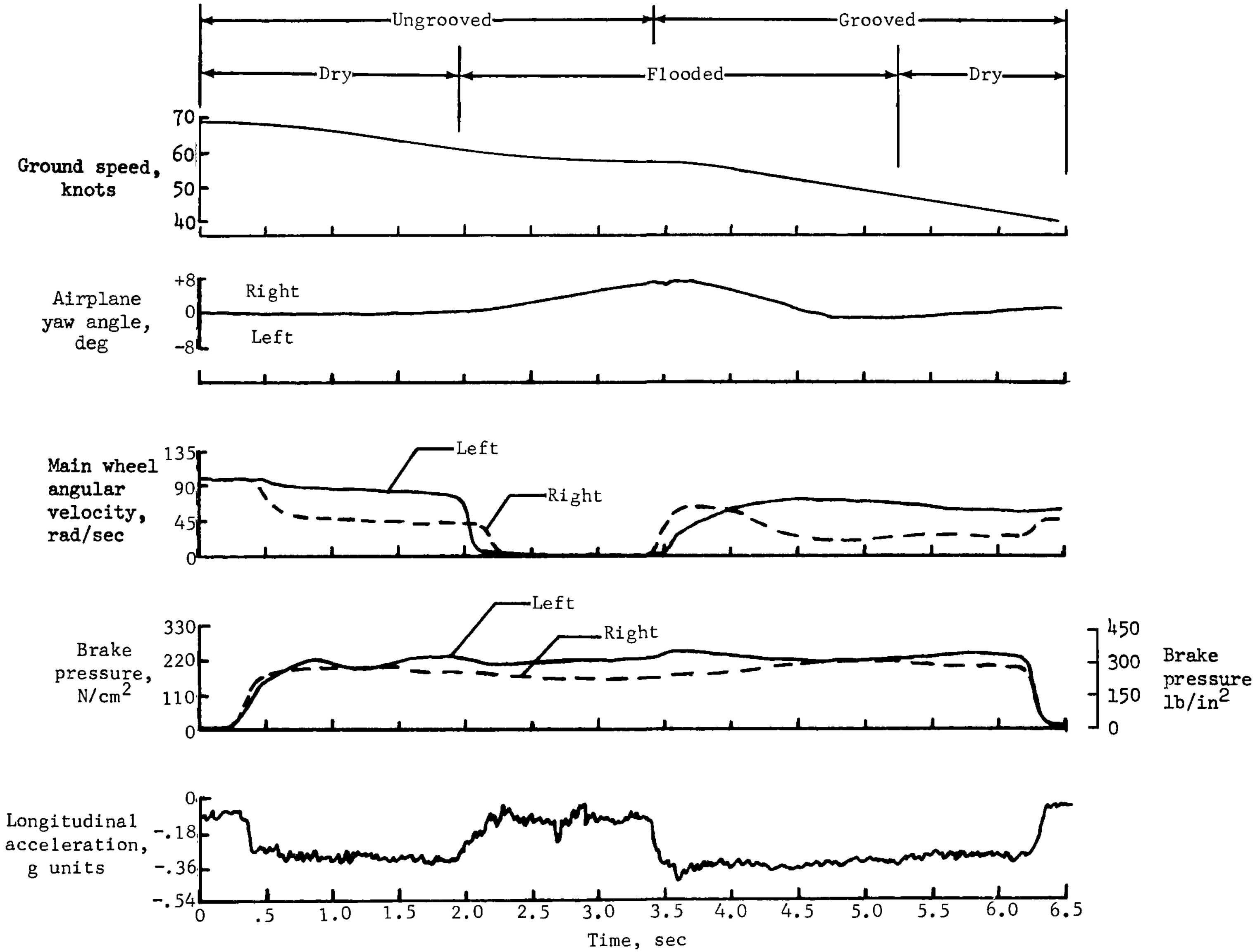
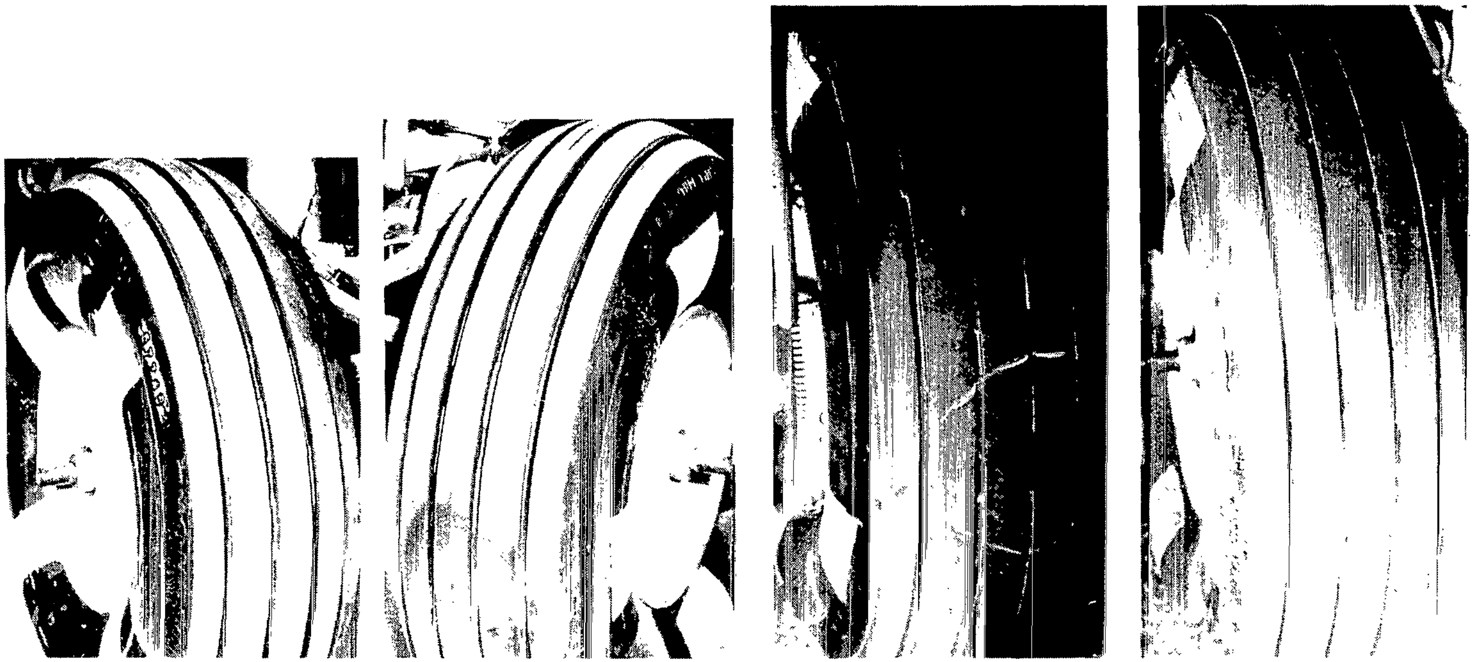


Figure 10.- Effect of flooded ungrooved and grooved surfaces on directional control of test airplane during maximum braking. Small-aggregate asphalt; 4-knot cross wind from right.



L-71-666

(a) New tread condition before tests.

(b) Worn tread condition after tests.

Figure 11.- Test-airplane main-gear tires. Four-groove, type III, 8.50 × 10 tires; inflation pressure, 32.4 N/cm^2 (47 lb/in^2).

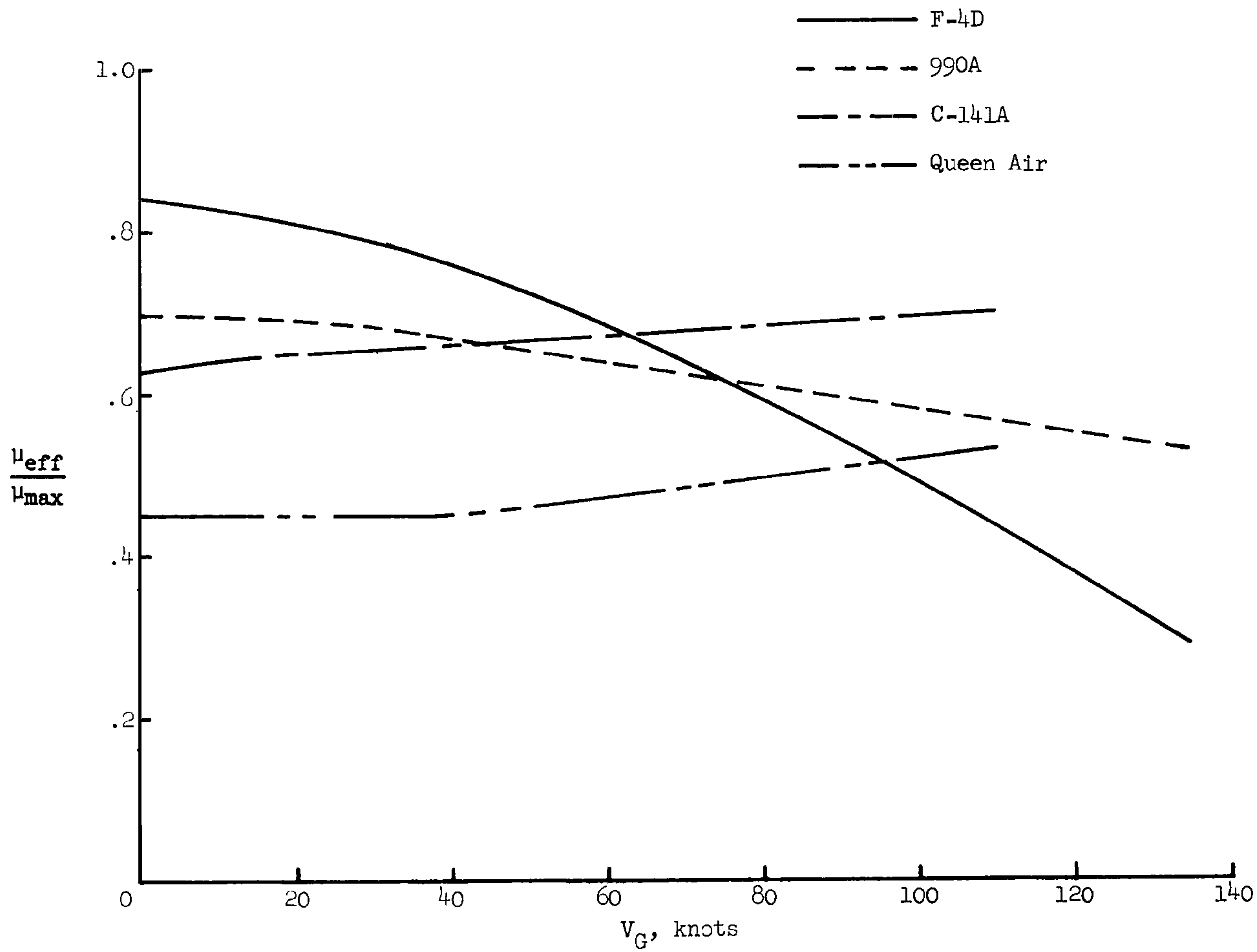
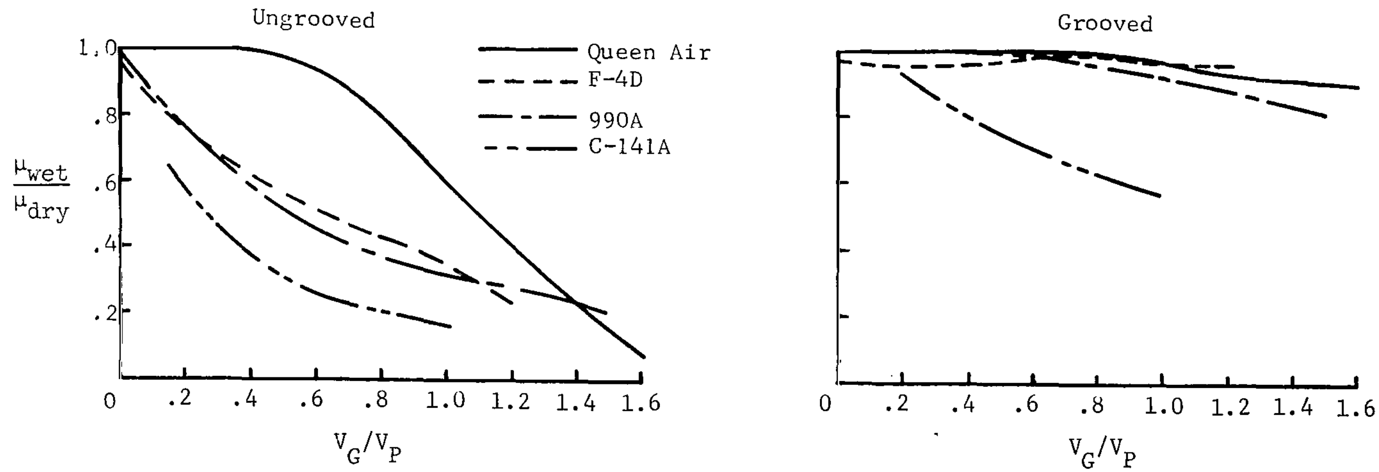
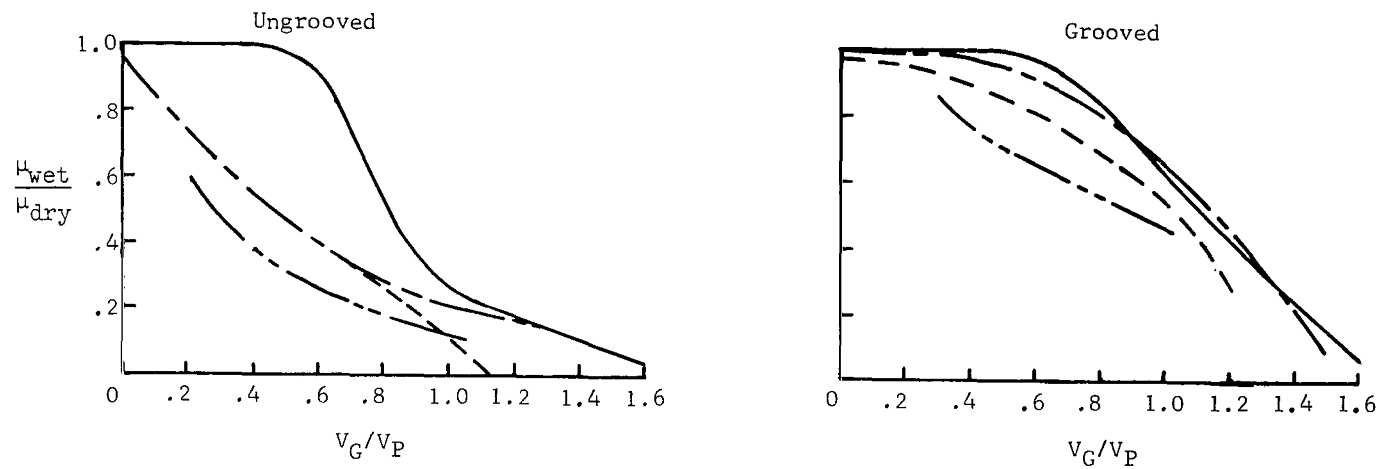


Figure 12.- Comparison of test-airplane braking efficiency on dry runways.



(a) Wet with isolated puddles.



(b) Flooded.

Figure 13.- Comparison of braking performance of Queen Air airplane and other test airplanes. Small-aggregate asphalt.

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